Enhancement of singly and multiply strangeness in p-Pb and Pb-Pb collisions at 158A GeV/c

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Abstract

The idea that the reduction of the strange quark suppression in string fragmentation leads to the enhancement of strange particle yield in nucleus-nucleus collisions is applied to study the singly and multiply strange particle production in p-Pb and Pb-Pb collisions at 158A GeV/c. In this mechanism the strange quark suppression factor is related to the effective string tension, which increases in turn with the increase of the energy, of the centrality and of the mass of colliding system. The WA97 observation that the strange particle enhancement increases with the increasing of centrality and of strange quark content in multiply strange particles in Pb-Pb collisions with respect to p-Pb collisions was accounted reasonably.

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I. INTRODUCTION

Strangeness as a possible signature of the phase transition from a hadronic state to a QGP state was put forward about 16 years ago [1]. It was based on the prediction that the production of strange quark pairs would be enhanced as a result of the approximate chiral symmetry restoration in a QGP state in comparison with a hadronic state. The strangeness enhancement in pA and AA collisions with respect to the superposition of nucleon-nucleon collisions has been investigated and confirmed by many experimental groups [2–6]. However, alternative explanations exist, they are based on the 'conventional' physics in the hadronic regime, like rescattering, string-string interaction, etc. [7–9]. The first detailed theoretical study of strangeness production can be found in [10], where the enhanced relative yield of strange and multi-strange particles in nucleus-nucleus collisions with respect to proton-nucleus interactions has been suggested as a sensitive signature of a QGP.

We have done a series of studies in recent years investigating strangeness enhancement with a hadron and string scenario [7,11–14], from which a Monte-Carlo event generator,

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LUCIAE, was developed [15]. Those studies indicate that including rescattering of the final state hadrons is still not enough to reproduce the NA35 [3] data of strange particle production. To reproduce the NA35 data needs to rely further on the mechanism of reduction of the strange quark suppression in string fragmentation, which contributes to the enhancement of strange particle yield in nucleus-nucleus collisions with respect to the superposition of the nucleon-nucleon collisions [11–14]. Similarly, in order to reproduce the NA35 data, the RQMD generator, equipped with rescattering though, has to resort to the colour rope mechanism [9]. In this picture it is assumed that the neighboring interacting strings might form a string cluster called colour rope in pA and AA collisions. The colour rope then fragments in a collective way and tends to enhance the production of the strange quark pairs from the colour field of strings through the increase of the effective string tension.

It has been known for years that the strange quark suppression factor (λ hereafter), i.e., the suppression of s quark pair production in the color field with respect to u or d pair production, in hadron-hadron collisions is not a constant, but energy-dependent, increasing from a value of 0.2 at the ISR energies to about 0.3 at the top of the SPS energies [16]. In [13] we proposed a mechanism to investigate the energy dependence of λ in hh collisions by relating the effective string tension to the production of hard gluon jets (mini-jets). A parameterization form was then obtained, which reproduces the energy dependence of λ in hh collisions reasonably well [13]. When the same mechanism is used in the study of pA and AA collisions it is found that λ would increase with the increase of energy, mass and centrality of a colliding system as a result of mini-jet(gluon) production stemming from the string-string interaction. Our model reproduced nicely the data of strange particle production in hh [13], pA, and AA [12,14] collisions.

In this work we use above ideas [13,14] to study the recently published WA97 data of the enhanced production of singly and multiply strange particles in p-Pb and Pb-pb collisions at 158A GeV/c. The study indicates that the WA97 data, which revealed that the enhancement of strange particle yield increases with the increasing of centrality and of s quark content in multiply strange particles in Pb-Pb collisions with respect to p-Pb collisions, could be explained in a hadron-string model except for Ω yield in the Pb-Pb data.

II. BRIEF REVIEW OF THE LUCIAE MODEL

LUCIAE model is developed based on the FRITIOF model [17]. FRITIOF is a string model, which started from the modeling of inelastic hadron-hadron collisions and it has been successful in describing many experimental data from the low energies at the ISR-regime all the way to the SPS energies [18,19]. In this model a hadron is assumed to behave like a massless relativistic string. A hadron-hadron collision is pictured as the multi-scattering of the partons inside the two colliding hadrons. In FRITIOF, during the collision two hadrons are excited due to longitudinal momentum transfers and/or a Rutherford Parton Scattering (RPS). The highly excited states will emit bremsstrahlung gluons according to the soft radiation model. They are afterwards treated as excitations i.e. the Lund Strings and allowed to decay into final state hadrons according to the Lund fragmentation scheme.

The FRITIOF model has been extended to also describe hadron-nucleus and nucleus-nucleus collisions by assuming that the reactions are superposition of binary hadron-hadron collisions in which the geometry of the nucleus plays an important role because the nuclei

should then behave as a "frozen" bag of nucleons. However in the relativistic nucleus-nucleus collisions there are generally many excited strings formed close by each other during a collision. Thus in the LUCIAE model a Firecracker model [20] is proposed to deal with the string-string collective interaction. In the Firecracker model it is assumed that several string from a relativistic heavy ion reaction will form a cluster and then the strings inside such a cluster will interact in a collective way. We assume that the groups of neighbouring strings in a cluster may form interacting quantum states so that both the emission of gluonic bremsstrahlung as well as the fragmentation properties can be affected by the large common energy density.

In relativistic nucleus-nucleus collision there are generally a lot of hadrons produced, however, FRITIOF does not include the final state interactions. Thus in LUCIAE a rescattering model [7] is devised to consider the reinteraction of the produced hadrons with each other and with the surrounding cold spectator matter. The distributions of the final state hadrons will be affected by the rescattering process. We refer to the Refs. [7,15] for the details and we just give here the list of the reactions involving in LUCIAE, which are cataloged into

$\pi N \rightleftharpoons \Delta\pi$	$\pi N \rightleftharpoons \rho N$
$NN \rightleftharpoons \Delta N$	$\pi\pi \rightleftharpoons k\bar{k}$
$\pi N \rightleftharpoons kY$	$\pi\bar{N} \rightleftharpoons \bar{k}\bar{Y}$
$\pi Y \rightleftharpoons k\Xi$	$\pi\bar{Y} \rightleftharpoons \bar{k}\bar{\Xi}$
$\bar{k}N \rightleftharpoons \pi Y$	$k\bar{N} \rightleftharpoons \pi\bar{Y}$
$\bar{k}Y \rightleftharpoons \pi\Xi$	$k\bar{Y} \rightleftharpoons \pi\bar{\Xi}$
$\bar{k}N \rightleftharpoons k\Xi$	$k\bar{N} \rightleftharpoons \bar{k}\bar{\Xi}$
$\pi\Xi \rightleftharpoons k\Omega^-$	$\pi\bar{\Xi} \rightleftharpoons \bar{k}\overline{\Omega^-}$
$k\bar{\Xi} \rightleftharpoons \pi\overline{\Omega^-}$	$\bar{k}\Xi \rightleftharpoons \pi\Omega^-$
$\bar{N}N$ annihilation	
$\bar{Y}N$ annihilation	

where Y refers to the Λ or Σ and Ξ refers to the Ξ^- or Ξ^0. There are 364 reactions involved altogether.

In addition, the reduction mechanism of s quark suppression, i. e., the s quark suppression factor increasing with energy, centrality, and mass of the colliding system, which is linked to string tension, is included in LUCIAE via the parameterized formulas [13,14]

$$\kappa_{eff} = \kappa_0(1-\xi)^{-\alpha}, \tag{1}$$

where κ_0 is the string tension of the pure $q\bar{q}$ string, α is a parameter ~ 3, and ξ (≤ 1) is calculated by

$$\xi = \frac{\ln(\frac{k^2_{\perp max}}{s_0})}{\ln(\frac{s}{s_0}) + \sum_{j=2}^{n-1}\ln(\frac{k^2_{\perp j}}{s_0})}, \tag{2}$$

which represents the scale that a multigluon string is deviated from a pure $q\bar{q}$ string.

The s quark suppression factor, λ, of two string states can thus be calculated by

$$\lambda_2 = \lambda_1^{\frac{\kappa_{eff1}}{\kappa_{eff2}}}, \tag{3}$$

where κ_{eff} refers to the effective string tension of a multigluon string. Since λ is always less than one, above equation indicates the larger effective string tension the more reduction of s quark suppression. The effective string tension is then relevant to the hard gluon kinks (mini-(gluon) jets) created on the string.

It should be mentioned that the LUCIAE (FRITIOF) event generator runs together with JETSET routine. In JETSET routine there are model parameters PARJ(2) (i.e., λ) and PARJ(3). PARJ(3) is the extra suppression of strange diquark production compared to the normal suppression of strange quark pair. Both PARJ(2) and PARJ(3) are responsible for the s quark (diquark) suppression and related to the effective string tension (the relation of Eq. (3) holds true for PARJ(3) as for λ). Besides λ and PARJ(3) there is PARJ(1), which stands for the suppression of diquark-antidiquark pair production in the color field in comparison with the quark-antiquark pair production and is related to the effective string tension as well. The mechanism mentioned above is performed via these parameters in program. How these three parameters affect the multiplicity distribution of final state particles can be found in [11,12].

III. RESULTS AND DISCUSSIONS

In Table 1 is given the results of the JETSET parameters PARJ(1), PARJ(2) (i.e., λ), and PARJ(3) varying with the centrality and the size of collision system in p-Pb and Pb-Pb collisions at 158A GeV/c. That seems quite reasonable.

Fig. 1a shows the calculated $\Lambda+\bar{\Lambda}$, $\Xi^-+\overline{\Xi^-}$, and $\Omega^-+\overline{\Omega^-}$ yields per event ($|y-y_{cm}|\leq 0.5$ and $p_T \geq 0$ GeV/c) as a function of the number of participant in minimum bias p-Pb collisions and in central (b=2) Pb-Pb collisions at 158A GeV/c (open labels) comparing with WA97 data (full labels) [5]. The corresponding results in Pb-Pb collisions after recaling each yield according to its value in p-Pb are given in Fig. 1b. One knows from Fig. 1a that the agreement between theory and experiment is quite well for $\Lambda+\bar{\Lambda}$ and $\Xi^-+\overline{\Xi^-}$, however, for $\Omega^-+\overline{\Omega^-}$ the theoretical results are lower than experiments. That should be study further both theoretically and experimentally. In Fig. 1b the theoretical results of $\Omega^-+\overline{\Omega^-}$ are also lower than experiments, however, the trend of the strangeness enhancement increasing with increase of the centrality and of the s quark content in strange particles is reproduced quite well.

In Fig. 2 and 3 are given, respectively, the calculated m_T spectra ($|y-y_{cm}|\leq 0.5$) of Λ, $\bar{\Lambda}$, Ξ^-, $\overline{\Xi^-}$ and $\Omega^-+\overline{\Omega^-}$ in p-Pb and Pb-Pb collisions at 158A GeV/c (open labels). The corresponding full labels in those figures are the corresponding WA97 data [5]. One sees from figure 2 that the agreement between theory and experiment is reasonably good, except that the fluctuation in theoretical results of $\Omega^-+\overline{\Omega^-}$ m_T spectrum has to be improved. However, the situations in figure 3 is much better, i.e., the agreement between theory and experiment is reasonably good.

In summary, we have used a hadron and string cascade model, LUCIAE, to investigate the WA97 data of the strangeness enhancement increasing with the increase of the centrality and of the s quark content in strange particles. Relying on the mechanism of the reduction of s quark suppression in string fragmentation leads to the enhancement of strange particle

yield in nucleus-nucleus collisions the WA97 data could be reproduced nicely except Ω yield in Pb+Pb collisions, which need to be studied further.

IV. ACKNOWLEDGMENTS

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Figure Captions

Fig. 1 a) The calculated $\Lambda + \bar{\Lambda}$, $\Xi^- + \overline{\Xi^-}$, and $\Omega^- + \overline{\Omega^-}$ yields per event ($|y - y_{cm}| \leq 0.5$ and $p_T \geq 0$ GeV/c) as a function of the number of participant in p-Pb and Pb-Pb collisions at 158A GeV/c (open labels) comparing with WA97 data (full labels) [5]. b) The calculated $\Lambda + \bar{\Lambda}$, $\Xi^- + \overline{\Xi^-}$, and $\Omega^- + \overline{\Omega^-}$ yields per event in Pb-Pb expressed in units of the corresponding yields in p-Pb as a function of the number of participant in Pb-Pb (open labels), the full labels are the corresponding WA97 data [5].

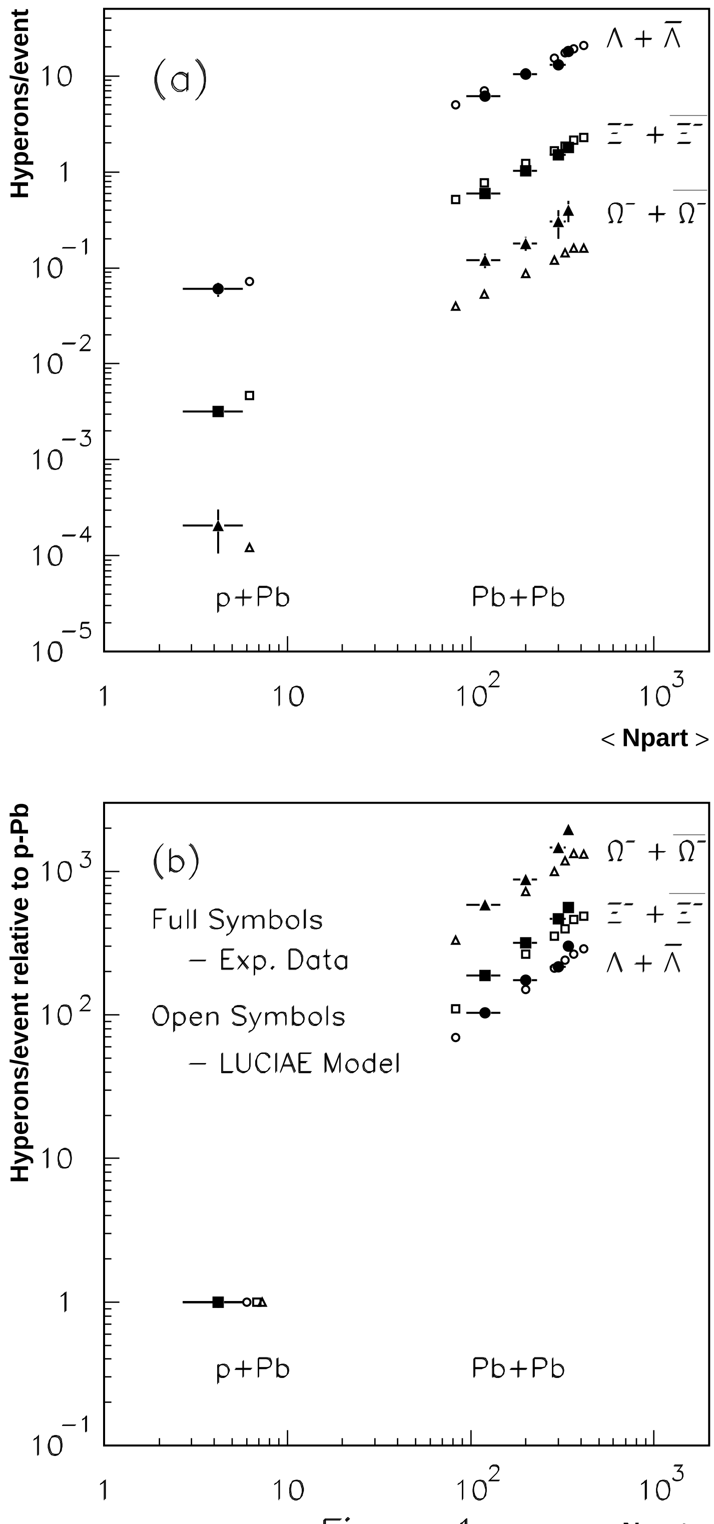
Fig. 2 The calculated m_T spectra ($|y - y_{cm}| \leq 0.5$) of λ, $\bar{\lambda}$, Ξ^-, $\overline{\Xi^-}$ and $\Omega^- + \overline{\Omega^-}$ in p-Pb collisions at 158 GeV/c (open labels) comparing with WA97 data (full labels) [5].

Fig. 3 The calculated m_T spectra ($|y - y_{cm}| \leq 0.5$) of λ, $\bar{\lambda}$, Ξ^-, $\overline{\Xi^-}$ and $\Omega^- + \overline{\Omega^-}$ in Pb-Pb collisions at 158A GeV/c (open labels) comparing with WA97 data (full labels) [5].

TABLES

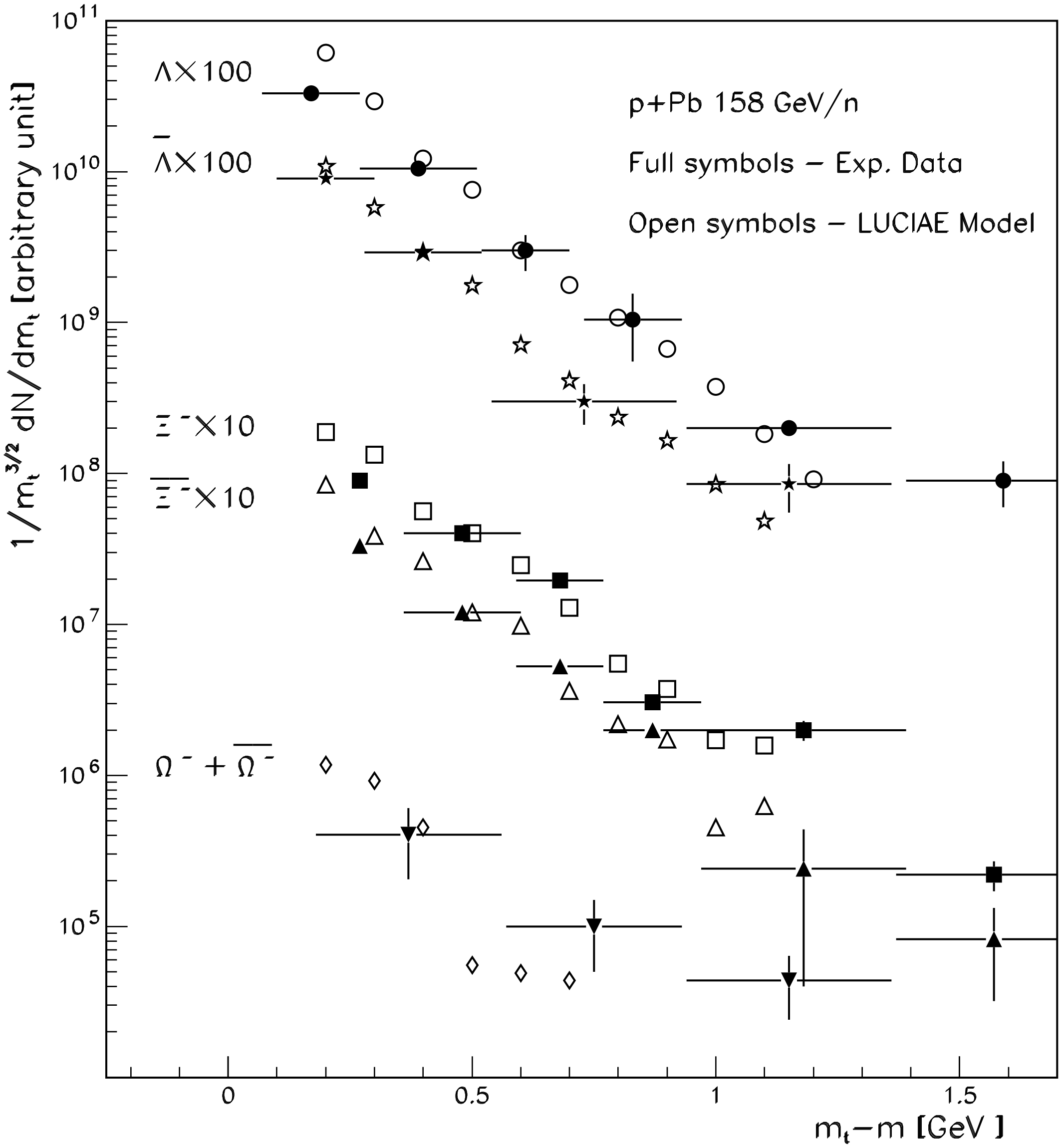
TABLE I. The values of the JETSET parameters in p-Pb and Pb-Pb collisions at 158A GeV/c

	p+Pb		Pb+Pb			
	b=0	b=5	b=0	b=2	b=4	b=6
PARJ(1)	0.0852	0.07734	0.1180	0.1171	0.1142	0.1105
PARJ(2)	0.2686	0.2577	0.3146	0.3134	0.3096	0.3048
PARJ(3)	0.3652	0.3549	0.4105	0.4093	0.4056	0.4010



(a)
Hyperons/event
$\Lambda + \bar{\Lambda}$
$\Xi^- + \overline{\Xi^-}$
$\Omega^- + \overline{\Omega^-}$
p+Pb
Pb+Pb
< Npart >
(b)
Hyperons/event relative to p-Pb
Full Symbols
– Exp. Data
Open Symbols
– LUCIAE Model
$\Omega^- + \overline{\Omega^-}$
$\Xi^- + \overline{\Xi^-}$
$\Lambda + \bar{\Lambda}$
p+Pb
Pb+Pb
< Npart >

Figure 1



p+Pb 158 GeV/n
Full symbols – Exp. Data
Open symbols – LUCIAE Model
$\Lambda \times 100$
$\bar{\Lambda} \times 100$
$\Xi^- \times 10$
$\bar{\Xi}^- \times 10$
$\Omega^- + \bar{\Omega}^-$
$1/m_t^{3/2}\, dN/dm_t$ [arbitrary unit]
$m_t - m$ [GeV]
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0
0.5
1
1.5

Figure 2

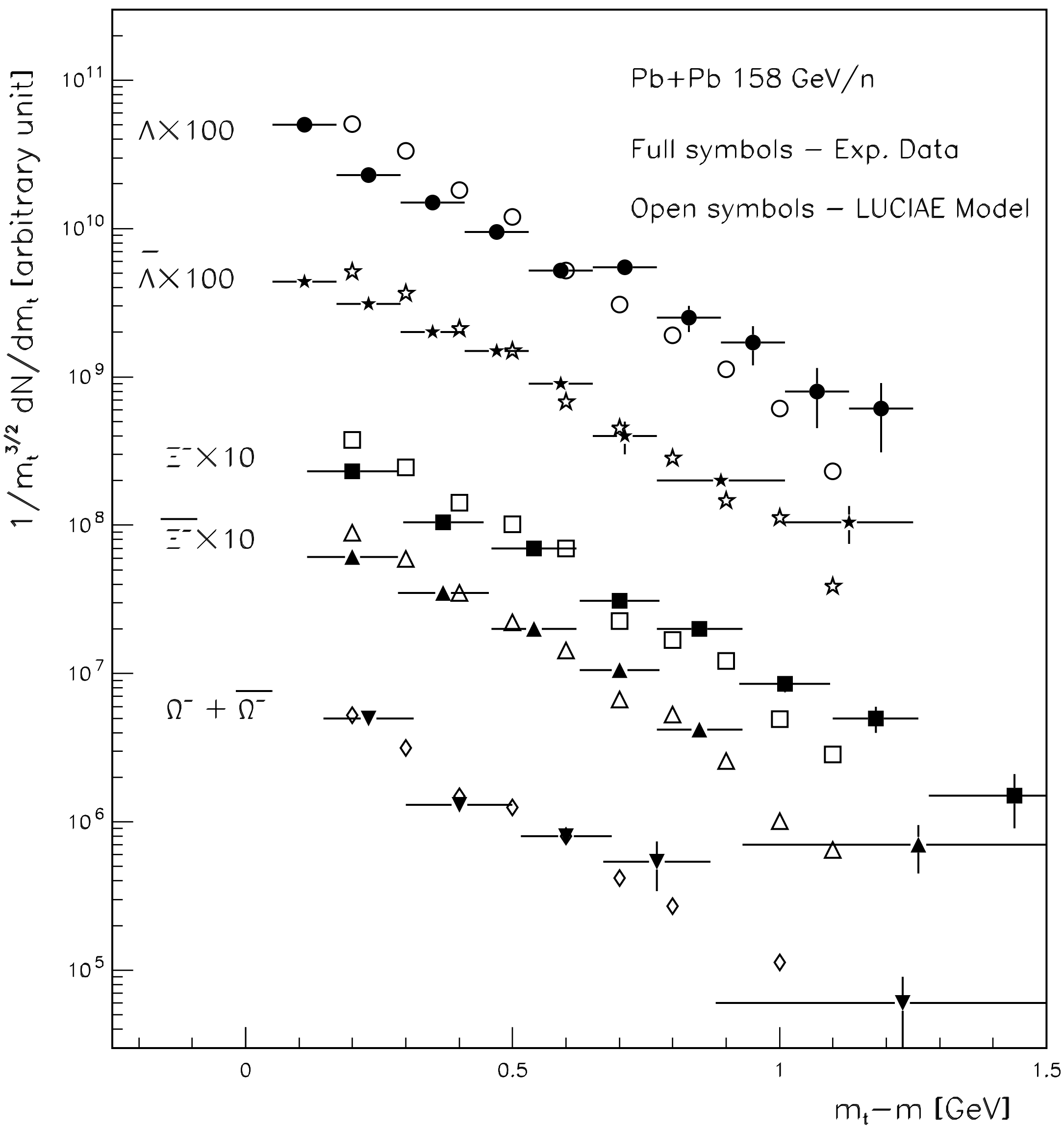

Pb+Pb 158 GeV/n
Full symbols – Exp. Data
Open symbols – LUCIAE Model
Λ×100
$\bar{\Lambda}$×100
Ξ⁻×10
$\bar{\Xi}$⁻×10
Ω⁻ + $\bar{\Omega}$⁻
1/m$_t^{3/2}$ dN/dm$_t$ [arbitrary unit]
m$_t$−m [GeV]
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
0
0.5
1
1.5

Figure 3